NIOSH FY2005 Project Form – Research Proposal Information Summary

<table>
<tr><td colspan="4">TITLE OF PROJECT</td></tr>
<tr><td colspan="4">Guidelines for Eliminating Hazardous Ground Conditions from Underground Stone Mines</td></tr>
<tr><td colspan="2">PROJ. OFFICER (Last, first, middle)</td><td colspan="2">DEGREE(S)</td></tr>
<tr><td colspan="2">Esterhuizen, Gabriel S.</td><td colspan="2">PhD, M.Eng., BSc(Eng) (Mining Engineering)</td></tr>
<tr><td colspan="2">POSITION TITLE</td><td colspan="2">MAILING ADDRESS (Street, city, state, zip code)</td></tr>
<tr><td colspan="2">Senior Service Fellow</td><td colspan="2" rowspan="5">NIOSH
Pittsburgh Research Laboratory
P.O. Box 18070
626 Cochrans Mill Road, Building 143, Room 209
Pittsburgh, PA 15236</td></tr>
<tr><td colspan="2">DIVISION/BRANCH</td></tr>
<tr><td colspan="2">Rock Safety Engineering</td></tr>
<tr><td colspan="2">TELEPHONE (Area code, number, and extension)</td></tr>
<tr><td colspan="2">412-386-5207</td></tr>
<tr><td colspan="2">FAX</td><td colspan="2">E-MAIL ADDRESS</td></tr>
<tr><td colspan="2">412-386-6718</td><td colspan="2">eee5@cdc.gov</td></tr>
<tr><td colspan="2">Will this project utilize human subjects?</td><td colspan="2">Will this project utilize vertebrate animals?</td></tr>
<tr><td colspan="2">YES: NO: X</td><td colspan="2">YES: NO: X
Species of animals to be used:
Approximate number of animals to be used:</td></tr>
</table>

<table>
<tr><td colspan="2" rowspan="2">DATES OF PROPOSED PERIOD OF SUPPORT (MM/DD/YYYY)</td><td colspan="5">NEW FUNDS REQUIRED (Do not include existing base funding)</td></tr>
<tr><td></td><td>PS&B</td><td>Other Intramural</td><td>Extramural</td><td>Total</td></tr>
<tr><td>From:</td><td>04/01/2005</td><td>FY2005</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Through:</td><td>09/30/2008</td><td>All Years</td><td></td><td></td><td></td><td></td></tr>
</table>

NEW FTEs	3.2	**% Project Category(s):**	100% Research
CURRENT FTEs	15.6	**% NORA Priority Area(s):**	0
TOTAL FTEs	18.8	**% Special Interest Areas(s):**	100% Mining
		% GPRA Category(s):	100% Research

DESCRIPTION.

Fall of ground accidents have been the largest single cause of fatalities in underground stone mines in the decade 1994 through 2003, while the fall of ground injury rates have remained essentially unchanged since 1995. The stability of the roof and ribs in underground stone mines can be improved by tailoring the excavation layout to the rock conditions. An engineered approach to stone mine design is needed which considers both the geotechnical properties of the surrounding rock and the imposed loads.

The room and pillar method is used in the majority of underground stone mines. The dimensions of the pillars and the roof spans in these mines are largely based on past experience without consideration of the geotechnical parameters that affect stability. A result is that large roof falls can occur unexpectedly and pillars are designed with questionable width-to-height ratios. In addition, anecdotal evidence seems to indicate that fluctuations in mine air temperature and humidity affect the mine stability. Guidelines are needed that will allow mine designers and operators to proactively design stable excavations to reduce the hazard of uncontrolled rock falls.

The objective of this project is to develop design guidelines for maximum roof spans and minimum pillar dimensions in underground stone mines. The effect of temperature and humidity on excavation stability will also be assessed and incorporated into the design guidelines.

The project has been subdivided into eight tasks to be carried out over a period of four years:

- Task1 - Geotechnical Data and Mine Characterization: Geotechnical and mining parameters will be collected from thirty underground stone mining operations in the Eastern and Midwestern States.
- Task 2: Back Analysis of Pillar Performance – Surveyed pillars will be evaluated in terms of loading and geotechnical characteristics.
- Task 3: Evaluate Pillar Strength at Low Width-to-height Ratios – Existing pillar design techniques and numerical models will be evaluated to establish factors important to pillar strength at low width to height ratios.
- Task 4: Analyze data and develop pillar design guidelines – All the collected data will be evaluated and guidelines will be developed for pillar design and layout, with a focus on pillars with low width-to-height ratios.
- Task 5 - Monitor and evaluate temperature and humidity effects: Monitoring of temperature and humidity changes and associated roof and rib stability issues will be conducted at three mine sites.
- Task 6 - Analyze roof span stability in stone mines: Collected field data, existing roof span design methods and numerical models will be utilized to identify appropriate criteria for designing stable roof spans.

- Task 7 - Case studies of roof span stability: Specific case study sites will be studied by field measurements and monitoring of roof behavior to identify failure and stability mechanics.
- Task 8 - Develop guidelines for selecting maximum roof span dimensions.

The outcome of the project will result in improved techniques for underground stone mine design, the elimination of potentially hazardous ground conditions and improved safety of the mine workers.

PERFORMANCE SITE(S) (organization, city, state)

1) Pittsburgh Research Laboratory’s Bruceton and Lake Lynn sites; PA.

2) Collaboration with various commercial stone mines throughout the U.S. and with MSHA is anticipated and most essential to the successful completion of this project.

KEY PERSONNEL

NAME	ORGANIZATION	ROLE ON PROJECT
Gabriel S. Esterhuizen	NIOSH	Principal Investigator – Mining/geotechnical specialist (Senior Service Fellow)
Dennis R. Dolinar	NIOSH	Project Engineer – Mining/geotechnical specialist (Mining Engineer)
R. Güner Gürtunca	NIOSH	Project Consultant (Acting Laboratory Director)
Anthony T. Iannacchione	NIOSH	Project Engineer - Mining/geotechnical specialist (Acting Team Leader Geotechnical Engineering)
Leonard J. Prosser	NIOSH	Project Geologist (Research Physical Scientist)
Stephen C. Tadolini	NIOSH	Overall project direction and performance (Branch Chief Rock Safety Engineering)

BIOGRAPHICAL SKETCH:

NAME	POSITION TITLE		
Gabriel S. Esterhuizen	Senior Service Fellow		
EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)			
INSTITUTION AND LOCATION	**DEGREE (If applicable)**	**YEAR(s)**	**FIELD OF STUDY**
University of Pretoria, South Africa	B.Sc. Eng.	1974	Mining Engineering
University of Pretoria, South Africa	M.Eng.	1991	Rock Engineering
University of Pretoria, South Africa	Ph.D.	1997	Rock Engineering

RESEARCH AND PROFESSIONAL EXPERIENCE:

1975 - 1980: Gold Fields of South Africa, Careltonville, South Africa.

Mining Engineer in Training, Rock Mechanics Engineer, Senior Rock Mechanics Engineer, Chief Rock Mechanics Engineer. After initial training period responsible for on-site rock engineering services to various deep gold mines with seismicity and high stress issues. Activities included support design, mine layout design, mine sequencing and quality monitoring. Ultimately responsible for Rock Mechanics Department serving two large underground gold mines.

1980 – 1982: Steffen Robertson & Kirsten Consulting Engineers, Johannesburg, South Africa.

Senior Mining Engineer. Rock Engineering consulting to a wide variety of mining and civil projects. Assignments included mine design for feasibility studies, stability of operating mines, hard rock room and pillar design, deep and high stress mine layout design, open pit stability and coal mine stability, groundwater and geohydrological studies.

1983 – 1999: University of Pretoria, Pretoria, South Africa.

Lecturer, Senior Lecturer, Associate Professor, Department of Mining Engineering. Responsible for undergraduate and graduate teaching in rock engineering. Research activities included issues such as coal mine pillar and barrier pillar design, gold mine design to mitigate seismicity, roof stability in deep gold mines. Conducted part-time consulting practice to gold, diamond, coal and base metal mines. Involvement as specialist in the International Caving Study Consortium, Brisbane, Australia.

1999-2003: SRK Consulting Inc., Denver, Colorado, USA.

Principal Mining Engineer. Consulting in rock engineering mainly to international clients in Australia, Africa, South America, Canada, Indonesia and Europe. Assignments included due diligence reviews for banking institutions, mine layout design for feasibility and operating mines and long term stability issues related to mine closure for both underground and surface mines.

2003-Present: NIOSH, Pittsburgh, PA, USA.

Senior Service Fellow. Involved in various projects including roof stability in stone mines, realistic numerical modeling of coal mine workings, groundwater and gas migration around coal workings, ground reaction curve analysis for coal mines and seismic analysis of fracturing around stone mine workings.

Awards and Honors:

The 1999 Salamon Award of the South African National Institute for Rock Engineering.

Relevant Publications:

Esterhuizen GS & AT Iannacchione, Investigation of pillar-roof contact failure in Northern Appalachian stone mine workings, Proc. 23rd International Conference on Ground Control in Mining, Morgantown, WV, pp. 320-326, 2004.

Esterhuizen GS, Jointing effects on pillar strength, Proc. 19th International Conference on Ground Control in Mining, Morgantown, WV, pp. 286-290, 2000.

Esterhuizen GS, Variability considerations in hard rock pillar design. Proc. Rock Engineering Problems Related to Hard Rock Mining at Shallow to Intermediate Depth, SANGORM, Rustenburg, South Africa, pp. 48-54, 1993

Esterhuizen GS, Investigations into the effects of discontinuities on the strength of coal pillars, J S Afr Inst Min Metall., v97, March/April 1997, pp 57 - 61 , 1997.

Page CH, Haines A & Esterhuizen GS, Design criteria for a room and pillar fluorspar mine, Proc 5th Int Congress on rock mechanics, Melbourne, Australia, pp D61 – D65, 1983.

Esterhuizen GS, Rock engineering evaluation of jointing in South African coal seams and its potential effect on coal pillar strength, in Mechanics of Jointed and Faulted Rock, Rossmanith (ed) Balkema, Rotterdam, pp 807 – 812, 1995.

Esterhuizen GS & Akermann KA, Stochastic keyblock analysis for stope support design, Int J Rock Mech & Min Sci, V 35 No 4 /5, p 397, 1998.

Esterhuizen GS & Streuders SB, Rockfall hazard evaluation using probabilistic keyblock analysis. J S Afr Inst Min Metall., v98 March/April 1998, pp 59 - 63 , 1998.

Esterhuizen GS, An improved method for the assessment of deep mine layouts using elastic models, 1st Southern African Rock Engineering Symposium, Johannesburg, pp 197 – 204, 1997.

BIOGRAPHICAL SKETCH.

NAME			**POSITION TITLE**
Dolinar, Dennis,Roger			Mining Engineer
EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)			
INSTITUTION AND LOCATION	**DEGREE (If applicable)**	**YEAR(s)**	**FIELD OF STUDY**
University of Minnesota, Minneapolis, MN	B S Mining Engineering	1973	Mining Engineering
Colorado School of Mines		1973-1974	Grad. courses in Rock Mechanics
West Virginia University	M S Mining Engineering	2004	Ground Control

RESEARCH AND PROFESSIONAL EXPERIENCE

1973 to 1980 U. S. Bureau of Mines, Denver Research Center
Mining engineer working on several project involved with ground control research. That included geothechnical and laboratory investigations for mine structural design. This research involved determination of in situ stress, determination of in situ and laboratory physical properties, and monitoring of instrumentation at field sites

1980 to 1996 U. S. Bureau of Mines, Denver Research Center
Principal investigator on ground control projects ground control research in both coal and metal non metal mines. These projects included Support of Large Underground Openings, Convergence Rates applied to Instability of Openings in Massive Evaporite Deposits, Energy Release induced by Caving in retreat Mining, Pillar reinforcement Techniques in Longwall Entries and Thrust Bolting, Ground Control Technology.

<u>1996 to present   National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory</u>

Evaluated the design and performance of roof support systems in underground coal mines resulting in the development of a database on primary roof support performance from 40 coal mines. Participated in the design and installation of several instrumented underground field sites to evaluate mine structure design and roof support. Conducted and completed a field evaluation and analysis of the innovative mining system “advance and relieve mining” a mining method used to reduce the affects of horizontal stress.

Presently, principal investigator on the project “Prevent Injuries from Fall of Ground in Underground Coal Mines.”. The major responsibilities include the planning and conducting of the project research and the technical supervision of project personnel.

Relevant Publications

Dolinar D,[2003]. Variation of Horizontal Stresses and Strains in Mines in Bedded Deposits in the Eastern and Midwestern United States. 19th Conference on Ground Control in Mining August 5-7, 2003, Morgantown, WV pp 178-185.

Dolinar D, Marshall T. Barczak T. Mucho, T [2003]. Stability of Underground Openings Adjacent to the sink hole at the NIOSH Lake Lynn Research Laboratory. SME Preprint 03-154, 7 pp.

Iannacchione T, Dolinar D, Mucho, T [2002]. High Stress Mining Under Shallow Overburden in Underground U. S. Stone mines. Proceedings of 1st International Seminar on Deep and High Stress Miing, Nov 6-8, Perth Australia.

Dolinar D, Mark C Molinda G[2001]. “Design of Primary Roof Support Systems in US Coal Mines Based on Analysis of Roof Fall Rates. 4th International Symposium on Roof Bolting in Mining, Aachen, Germany, June 6 and 7 2001 pp235-252.

Dolinar D, Mucho T, Oyler D, Pablic J [2000]. “Advance and Relieve” Mining, A Method to Mitigate the Affects of High Horizontal Stress on the Mine Roof. Presented at SME annual meeting Feb 26-28 2001, SME Preprint 01-113.

Dolinar D, Martin L [2000]. Cable Support in Longwall Gateroads. In: Proceedings of New Technology in Coal Mine Roof Support. Pittsburgh, PA. NIOSH IC 9453, pp 165-192.

Mark C, Dolinar D, Mucho T [2000]. Summary of Field Measurements of Roof Bolt Performance In: Proceedings of New Technology in Coal Mine Roof Support. Pittsburgh, PA. NIOSH IC 9453, pp 81-98.

Molinda G, Mark C, Dolinar D [2000]. Assessing Coal Mine Roof Stability Through Roof Fall Analysis In: Proceedings of New Technology in Coal Mine Roof Support. Pittsburgh, PA. NIOSH IC 9453, pp.

Dolinar, D. R., Mucho, T., Oyler, D. C. and J. Pablic. Utilizing the "Advance and Relieve Method to Reduce Horizontal Stress affects on the Mine Roof, A Case Study. 19th Conference on Ground Control in Mining August 7-9, 2000, Morgantown, WV.

Dolinar, D. R. and L. Martin. Cable Support in Longwall Gateroads. In New Technology for Coal Mine Roof Support. NIOSH Special Publication, 2000.

Dolinar, D. R., Oyler, D. C. and C. S. Compton. Analysis of Extensometer Data from a Room Widening Experiment Designed to Induce a Roof Fall. In Proceedings 16th Conference on Ground Control In Mining, August 5-7, 1997, Morgantown, WV, pp 289-295.

BIOGRAPHICAL SKETCH

NAME	POSITION TITLE		
Stephen C. Tadolini	Acting Branch Chief , Rock Safety Engineering Branch		
EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)			
INSTITUTE AND LOCATION	DEGREE (If applicable)	YEAR(s)	FIELD OF STUDY
West Virginia University, Morgantown, WV	Ph.D.	2003	Mining Engineering
University of Colorado, Denver, CO	M.S.	1988	Civil and Geotechnical Engineering, Rock Mechanics
University of Colorado, Denver, CO	B.S.	1979	Civil and Environmental Engineering

RESEARCH AND PROFESSIONAL EXPERIENCES:

Employment and Experience:
2002- Present: Currently Acting Branch Chief, Rock Safety Engineering Branch, National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA. Responsible for management of multi-disciplinary research team conducting safety and health research in the areas of geotechnical engineering, rock mechanics, and ground control.

1999 - 2002: Vice President of Engineering and Research, Excel Mining Systems, Inc., Cadiz, OH.
Responsible for new product development in the areas of underground metal/non-metal and coal ground control products. Conduct mine stability analysis and make cost-effective ground control recommendations to increase safety and enhance stability. Co-ordinate Company engineering and research program and direct technical field efforts and reporting.

1996 - 1999: Manager of Technical Services, Excel Mining Systems (Division of ANI) with manufacturing and engineering design and support in Australia, United States, Poland, Chili, and United Kingdom.
Served as the Team Leader of an International research team with the task of addressing ground control issues in the U.S., Australia, Poland, United Kingdom, and Chili. The findings of the team were submitted to senior management as research proposals, were selected on merit, and conducted for execution into ground control product innovations.

1995 - 1996: Vice President, Technical Services, Rocky Mountain Bolt Co., Denver, CO.
Broad engineering, consulting, and management responsibilities, in the area of ground control and underground mine design.

1986 - 1995: Principal Investigator, U.S. Bureau of Mines, Denver Research Center, Denver. CO.
Management responsibilities in the area of ground control, rock mechanics, support system design and selection, and new product development. Received 37 Special Achievement Awards and 4 Quality Step Increases.

1980 - 1986: Mining engineer, U.S. Bureau of Mines, Denver Research Center, Denver. CO.
Mining research in the areas of rock mechanics, mine design, and ground control, including drilling and instrumentation installation and data interpretation.

1979 - 1980: Geotechnical project engineer, Chen & Associates, Consulting Geotechnical Engineers, Denver, CO.
Performed on-site and laboratory analysis of soil and rock mechanics behaviors.

Society Memberships:

Member of Society of Mining, Metallurgy, and Exploration Engineers (1980)
Member of International Society of Rock Mechanics (1990)
Member of Colorado Mining Association (1982)
Member of American Rock Mechanics Association (2004)

Professional Activities:

1998 - 2005 Organizing Committee of International Ground Control Conference, WVU
2003-2005 Publication Committee of SME
1996 - 2002 ASTM Committee Member on ASTM-432, Standard Specifications for Roof and Rock Bolt Accessories.
1998 - 2002 American Mining Congress, Special Committee on Cable Supports.

Selected Publications:

Tadolini, S. C. and T. M. Barczak. Design Parameters of Roof Support Systems for Pre-Driven Longwall Recovery Rooms. SME Annual Meeting, Denver, CO, February 23-25, 2004. SME Preprint 05-54. Submitted for Peer-Review for SME Transactions.

Barczak, T. M. and S. C. Tadolini. Inflatable Hydraulic Bladders: An Innovation in Roof Support Technology. The 23rd International Conference on Ground Control in Mining, Morgantown, WV, August 3-5, 2004. pp. 286-294.

Barczak, T. M. and S. C. Tadolini. Standing Support Alternatives for Western Longwalls. SME Annual Meeting, SLC, UT, February 28-March 2, 2005.

Tadolini, S. C., Barczak, T. M., and Y. Zhang. The Effect of Standing Support Stiffness on Primary and Secondary Bolting Systems. The 22nd International Conference on Ground Control in Mining, Morgantown, WV, August 5-7, 2003.

Tadolini, S. C., Y. Zhang, and S. S. Peng. The Use of Pre-Driven Longwall Recovery Rooms Under Weak Roof Conditions - Design, Implementation, and Evaluation. Paper in Proceedings of the 21st International Conference on Ground Control in Mining, Morgantown, WV. August 6-8, 2002, pp. 1-10.

Tadolini, S. C. and H. S. Mitri. Field and Numerical Analysis of Resin-Grouted Cable Bolts Used for Coal Mine Longwall Roof Support. Paper in Proceedings of the 5th North American Rock Mechanics Symposium, Toronto, Canada. NARMS-TAC 2002, Hammah et al. (eds) ISBN 0 7727 6708 4, University of Toronto, July 7-10, 2002. pp 841-849.

Tadolini, S. C. and D. R. Dolinar. Enhanced Surface Control for Roof and Rib Support. Paper in Proceedings of the 20th International Conference on Ground Control in Mining, Morgantown, WV. August 7-9, 2000, pp.173-179.

Tadolini, S. C., P. W. Kraus, and A. Worbois. High Capacity Tensioned Cable Bolts for Tailgate Support. Paper in Proceedings of the 19th International Conference on Ground Control in Mining, Morgantown, WV. August 8-10, 2000, pp.59-66.

Tadolini, S. C., J. L. Gallagher, and J. M. Goris. Resin-grouted Cable Supports for Coal Mine Ground Control. The Canadian Mining and Metallurgical Bulletin, Volume 92, No. 1028, March 1999, 135-139 pp.

Tadolini, S. C. and G. Hendon. The Effects of Reduced Annulus in Roof Bolting Performance. Paper in Proceedings of the 17th International Conference on Ground Control in Mining, Morgantown, WV. August 4-6, 1998, pp. 231-236.

Tadolini, S. C., McDonnell, J. P. and K. F. Hollberg. Recent Developments in Cable Support Technology. SME Annual Meeting & Exhibit, Orlando, FL, March 9-11, 1998. SME Pre-Print 98-26.

Rico, G. H., R. Orea, R., Tadolini, S. C., and R. Mendoza L. Implementation and Evaluation of Roof Bolting in MICARE Mine II. Paper in Proceedings of the 16th International Conference on Ground Control in Mining, Morgantown, WV. August 5-7, 1997, pp. 139-148.

Tadolini, S. C. Roof Support Selection Criteria. Proceedings of Safety Seminar for Underground Stone Mines. Evansville, IN, December 10, 1997. pp. 12-14.

Dolinar, D. R., and S. C. Tadolini. High Horizontal Movements in Longwall Gate Roads Controlled by Cable Support Systems. Paper in Proceedings of the 15th International Conference on Ground Control in Mining, Colorado School of Mines August 13-15, 1996, pp. 497-509.

Tadolini, S. C., J. L. Gallagher, and J. M. Goris. Resin-Grouted Cable Support for Coal Mine Ground Control. 97th Annual General Meeting of the CIM, Halifax, Nova Scotia, May 14-18, 1995.

BIOGRAPHICAL SKETCH

NAME	POSITION TITLE		
Anthony Iannacchione	Acting Team Leader , Geotechnical Section, Rock Safety Engineering Branch		
EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)			
INSTITUTE AND LOCATION	DEGREE (If applicable)	YEAR(s)	FIELD OF STUDY
University of Pittsburgh, Pittsburgh, PA	Ph.D.	1997	Civil Engineering
University of Pittsburgh, Pittsburgh, PA	M.S.	1990	Civil Engineering
University of Pittsburgh, Pittsburgh, PA	M.S.	1977	Geology
California University of Pennsylvania, California, PA	B.S.	1975	Geology

RESEARCH AND PROFESSIONAL EXPERIENCES:

Employment and Experience:

From: November 2004 to Present: Acting Team Leader, Geotechnical Section, Rock Safety Engineering Branch, Pittsburgh Research Laboratory (PRL), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Pittsburgh, PA. Responsible for management of multi-disciplinary research team conducting safety and health research in the areas of geotechnical engineering.

From: March 2002 to November 2004: Senior Scientist, Disaster Prevention and Response Branch, PRL, NIOSH, CDC. Lead scientist in the following topic areas within the Ground Control programmatic research area: 1) increasing miner awareness to strata instabilities by promoting the use of various geomechanical instrumentation, including stress measurements, deformation monitoring, and/or microseismic networks; and 2) reducing miner exposure to unstable ground by advancing the fundamental understanding of rock failure processes principally through the application of state-of-the-art numerical and geologic models.

From October 1998 to March 2002: Deputy Director, PRL, NIOSH, CDC. The Deputy Director assisted the Director with planning, developing, evaluating and managing the programs of the laboratory. Provided leadership for the prevention of work-related illness and injury of miners through the management of three Branches and one Activity: 1) Disaster Prevention and Response Branch, 2) Health Branch, 3) Mining Injury and Prevention Branch, and 4) Surveillance, Statistics, and Research Support Activity. The Pittsburgh Research Laboratory has a staff of over 200 FTEs, with an annual budget of approximately 18 million dollars. The work force is composed of various occupations and groups of professional, technical, and administrative staff. Dr. Iannacchione was involved in program planning, resource allocation, awards and promotions, hiring, disciplinary actions, stakeholder interactions, and budget formulation and approval.

From August 1998 to September 1998: Acting Director, PRL, NIOSH, CDC. See above for a list of duties.

From May 1998 to August 1998: Acting Deputy Director, PRL, NIOSH, CDC. See above for a list of duties.

From October 1997 to April 1998: Acting Team Leader, Rock Mechanics Group, PRL, NIOSH, CDC. Directed a staff of 12 engaged in research to lower falls of ground injuries associated with mining by transferring existing technology and developing engineering design tools which emphasize safety. Frequently acted for the Branch Chief of the Disaster Prevention and Response Branch (~90 people).

From January 1999 to October 1997: Supervisory Civil Engineer: Rock Mechanics Group, Pittsburgh Research Center (PRC) under NIOSH, the U.S. Department of Energy (DOE), and the U.S. Bureau of Mines (USBM). Similar duties to those stated above for the Active Team Leader position. Frequently acted for the Research Supervisor of the Ground and Methane Control Group (45 people). One acting period lasted for 4 month from April 2 to July 2, 1995.

From June 1984 to January 1991: Supervisory Geologist, Geologic Studies Group, PRC, USBM. Supervised a team of approximately 14 geologist, engineers, and technicians. This team was tasked to investigate the geologic factors responsible for hazards ground conditions in underground coal mines and the fundamental factors responsible for coal mine bumps.

From June 1975 to June 1984: Geologist, Geologic Studies Group, PRC, USBM. Conducted research into the generation, retention, and liberation of methane gas in geologic formations associated with active mining districts. This knowledge was used to develop mine specific methane control programs. The work in the Arkoma Basin of Oklahoma and Arkansas was used to develop strategies for commercial extraction of the methane gas. The work in domal salt mines was used as the scientific rationale for the development and implementation of MSHA's gassy mine standards for nonmetal underground mines.

Society Memberships:

1. American Society of Civil Engineers (1990 – present)
2. Society of Mining Engineers (1998-present)
3. Pittsburgh Geological Society (2002-present)
4. American Rock Mechanics Association (2004)
5. Professional Engineer, PE-045672-E, Commonwealth of Pennsylvania, 1996-present

6. Professional Geologist, PG-000050-G, Commonwealth of Pennsylvania, 1994-present

Professional Activities:

- Leadership of the Pittsburgh Section, American Society of Civil Engineers (2003-05), serving as Vice-President, President and now Past-President. The Pittsburgh Section contains approximately 1,500 members. The role of the Pittsburgh Section President is to uphold the section's Constitution and ByLaws, keep the section organized, preside over meetings, recognize peoples efforts, correspond with Society Officials/other-organizations/individuals, participate in the District 4 Council, help defuse problems, and most of all, provide leadership through an articulated vision and a clear set of goals.
- Participated in the Society of Mining Engineers: 1) performed a technical review or the paper entitled "Performance of Coal Mine Pillars Under Varying Roof and Floor Conditions", 2) Chair of Geomechanics Session at the 2003 SME Annual Meeting, and 3) member of the SME Senior Project Award Committee.
- Member of the organizing committee for the 2005 Rock Mechanics Symposium, Anchorage, Alaska, June, 2005. Responsible for the organizing the plenary panel discussion and the session on Geophysical Methods.

Selected Publications:

<u>First author over the last 3 years</u>

"Characterising Roof Fall Signatures from Underground Mines" by A.T. Iannacchione, M.Chapman, and L.Burke, (11 pages) approved for publication by the organizing committee of the 6th International Symposium on Rockburst and Seismicity in Mines. Scheduled for publication and presentation on March 11, 2005, Perth, Australia.

"Relationship of Roof Movement and Strata Induced Microseismic Emissions to Roof Falls", by A.T. Iannacchione, P.R. Coyle, L.J. Prosser, T.E. Marshall, and J. Litsenberger, <u>Mining Engineering</u>, December, 2004, pp. 53-60 also published as SME PrePrint #04-58, SME Annual Meeting, Denver, CO, Feb. 23-25 2004.

"Mapping Hazards with Microseismic Technology to Anticipate Roof Falls – A Case Study", by A. Iannacchione, T. Batchler, and T. Marshall, Proceedings of the 23rd International Ground Control Conference, Morgantown, WV, Aug. 3-5, 2004, pp. 327-333.

"Safer Mine Layouts for Underground Stone Mines Subjected to Excessive Levels of Horizontal Stress", by A.T. Iannacchione, T.E. Marshall, L. Burke, R. Melville, and J. Litsenberger, <u>Mining Engineering</u>, April 2003, pp. 25-31.

"100 Years of Improvement in Aggregate Worker Safety", by A.T. Iannacchione and T.P. Mucho, Stone, Sand and Gravel Review, March/April 2003, pp. 28-34.

"An Examination of the Loyalhanna Limestone's Structural Features and Their Impact on Mining and Ground Control Practices", by A.T. Iannacchione and P. Coyle, 21st Intern. Conf. On Ground Control in Mining, Morgantown, WV, Aug. 6-8, 2002, pp. 218-227.

"High Stress Mining Under Shallow Overburden in Underground U.S. Stone Mines", by A.T. Iannacchione, D.R. Dolinar, and T.P. Mucho, Intern. Seminar of Deep and High Stress Mining, Australian Centre for Geomechanics, Section 32, Perth, Australia, Nov. 6-8, 2002, pp. 1-11.

Co-authored over the last 3 years

"Improving Source Location Accuracy for Mine Microseismic Monitoring: A Case Study", by M. Ge, M. Mrugala, and A. Iannacchione, International Journal of Rock Mechanics, in press.

"Numerical Modeling for Increased Understanding of the Behavior and Performance of Coal Mine Stoppings", by L. Burke, A. Iannacchione, and T. Barczak, Proceedings of the 23rd International Ground Control Conference, Morgantown, WV, Aug. 3-5, 2004, pp. 112-118.

"Investigation of Pillar-Roof Contact Failure in Northern Appalachian Stone Mine Workings", by G. Esterhuizen and A. Iannacchione, Proceedings of the 23rd International Ground Control Conference, Morgantown, WV, Aug. 3-5, 2004, pp. 320-326.

"Considerations for Using Roof Monitors in Underground Limestone Mines in the USA", by Prosser, L., T. Marshall, S. Tadolini, A. Iannacchione, and C. Banta, 22nd Intern. Conf. on Ground Control in Mining, Morgantown, WV, Aug. 5-7, 2003, pp. 119-126.

Part B: Research Proposal, Personnel Plan, and Budget

THE RESEARCH PLAN

a) Specific Aims

Objective 1: Develop guidelines for minimum pillar width-to-height ratios in underground stone mines

Objective 2: Develop guidelines for maximum roof span dimensions in underground stone mines

Objective 3: Determine the effect of changes in temperature and humidity on roof and rib stability in underground stone mines

b) Background and Significance

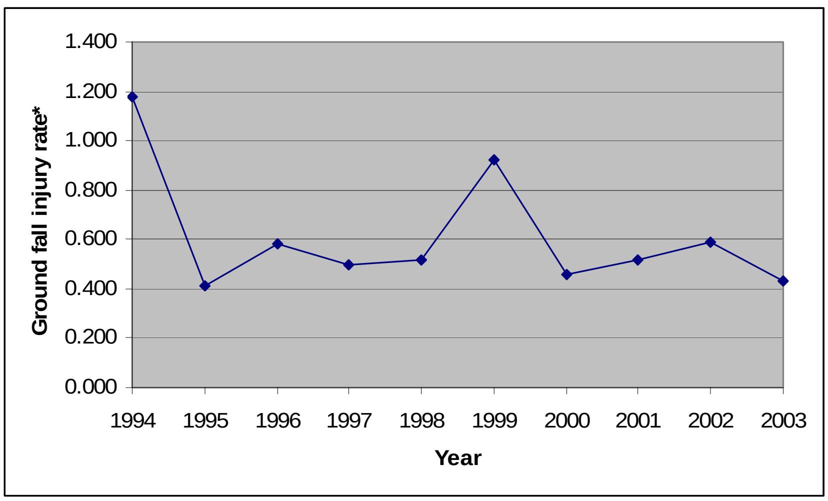

Figure 1: Ground fall injury rate in underground stone mines 1994 to 2003

Ground fall accidents have accounted for 45% of all fatalities in underground stone mines over the past decade. Accident statistics from the Mine Safety and Health Administration (MSHA, 2005) database indicate that the fall of ground injury rate (per 200,000 hrs worked) in underground stone mines during 2003 was 0.433 compared to 1.51 for underground coal mines and 1.34 for all underground mining in the US. The trend in the fall of ground injury rate has been decreasing over the past several decades, but has remained essentially unchanged since 1995, as shown in Figure 1. The ground fall hazard in stone mines is exacerbated by:

- The large opening dimensions which make it difficult to identify unstable roof.
- Rock falls can be large and can have devastating effects owing to the great fall distance.
- The large dimensions make it difficult to access the roof for remedial action.
- Small rocks can have serious consequences if they fall from a great height.

Many underground stone mines use the room-and-pillar method of mining in which stable pillars are required to support the overburden and stable roof spans are required to provide access to the working face. A conflict exists between production requirements and safety because larger openings are required for increased productivity but the stability of the roof decreases with increasing dimensions. A further conflict exists between the need to extract a high proportion of the underground reserves and the stability of the pillars to support the overburden. As the pillars become smaller their strength is reduced but the load increases, potentially overloading the pillars.

The stability of the roof and the support pillars depends on the quality of the rock mass as well as the imposed loads from the overburden and near surface tectonic stresses. Variations exist in rock mass properties, overburden loads and tectonic stresses that require the mine layout and support systems to be adjusted to maintain safe working conditions. It is therefore necessary to quantify the rock mass quality, the overburden loading and tectonic stresses to design stable mine excavations.

<u>Problem Area 1: Pillars with low width-to-height ratios</u>

The strength of a pillar depends on the strength of the rock that forms the pillar as well as the width-to-height ratio. A reduction in the width-to-height ratio causes a reduction in the overall strength of the pillar. In stone mines the following issues have been identified regarding pillars with low width-to-height ratios:

- Pillars are often developed to an initial height of about 25 ft but this can be followed by benching of the floor, which can increase the height to 60 ft or more. The slender pillars in the benched areas will be weaker than in the original development and can fail when their strength decreases owing to the reduction in width-to-height ratio.
- Pillars that were initially stable during development can become unstable during benching. NIOSH researchers have observed that benching operations were abandoned in several underground stone mines owing to the deterioration of rock conditions in the benched area.
- Large scale collapse of the overburden can occur if the failure of one pillar overloads the adjacent pillars, setting off a chain-reaction. The likelihood of a chain-reaction of failures is enhanced if the pillars are slender.
- Pillars with reduced width-to-height ratios are sensitive to the weakening effect of through-

Figure 2: Pillar with a low width-to-height ratio in a stone mine

going joints or slips. In stone mines the rock mass can be generally very good, but the presence of a single slip or fault can initiate unexpected stability problems, especially in slender pillars

Empirical pillar strength equations have been developed for coal and base metal mines. These equations are not applicable outside their empirical basis and should not be used for the design of stone mines. They also do not adequately address strength at low width to height ratios often found in stone mines, such as the pillar shown in Figure 2. At present stone mine pillar dimensions are determined largely from past practices or the trail-and-error approach. Consequently stone mines use pillars with questionable width to height ratios. A methodology for designing pillars in stone mines, with an emphasis on pillars at low width-to-height ratios, is clearly needed.

Problem Area 2: Maximum Roof Span Dimensions

Stone mine operators have a desire to maximize roof spans for production purposes. Owing to the bedded nature of limestone formations, the immediate roof is likely to consist of one or more rock beams that are parallel to the roof. The stability of these beams depends on the rock characteristics and loading of the beam by overburden or tectonic stresses. Typical roof spans in stone mines are 43 ft, and spans of up to 60 ft are used. As the roof span increases, the stability of the rock beams can decrease for the following reasons:

- Increased deflection can result in buckling or tensile failure of the rock beams.
- Bending stresses in the rock beams increase and can result in failure of the intact rock in tension or shear.
- The likelihood of intersecting unfavorable joints or slips increases.

Figure 3: Failure of the immediate roof beam in a stone mine

An example of failure of the immediate roof beam is shown in Figure 3. Similar to pillar design, roof span dimensions are determined largely from previous experience or by a trial-and-error approach. Methods to account for site specific ground and stress conditions do not exist. Methods developed for metal and coal mines are sometimes used, but do not adequately address the bedded nature of limestone rocks.

Problem Area 3: Changes in Temperature, Humidity, and Air Flow

A particular concern in underground stone mines is that the ground fall frequency during August and September is nearly twice that of December and January. Reasons typically given for the higher number of ground falls in the summer months are:

- Production rates are also higher in the summer months. This would result in a higher rate of exposure of new roof, with an increase in the likelihood of exposing unstable roof.
- During the summer months the air temperature and humidity increases. The presence of moisture sensitive layers in the roof strata and along rock joints can induce instability.
- Air flow directions can change, causing entries that were in fresh intake air to be exposed to saturated return air. Moisture sensitivity of the rocks can result in instabilities under the changed conditions.

No published or reliable data exist to determine the validity of these explanations. A limited amount of work has been done to evaluate the effect of mine climate changes on weak coal mine roof and sensitivity of weak rocks to moisture changes. These results do not address the conditions in underground limestone mines.

c) Preliminary Studies / Progress Report

Previous and current NIOSH projects related to stone mine stability:

Stability in stone mines has been targeted for research by NIOSH since 1996. Roof beam stability was investigated by field monitoring of deflection, showing that accelerated rates of deflection occur prior to roof falls (Prosser et al., 2003; Marshall et al. 2000). The effectiveness of different types of rock bolts was investigated through a detailed program of field monitoring and analysis. The findings were published (Iannacchione et al. 1997) and recommendations made regarding beam stability issues and roof bolt selection. A roof deflection monitoring system, called the RMSS, was developed and its used in operating mines was promoted by site visits to mines and through industry seminars. Guidelines for stone mine layout design were produced in which the issues associated with pillar design (Iannacchione, 1999) and layout in high stress conditions, (Iannacchione et al. 2003) were addressed. The potential hazard of pillars with low width-to-height ratios was clearly identified in these studies. In addition, the existence of large roof spans, many of which are unsupported, was recognized.

A current NIOSH project titled “Fundamental studies of factors responsible for roof falls” has investigated micro seismic emissions associated with roof falls in stone mines (Iannacchione, 2003) and evaluated the causes of unique roof failures in stone mines (Esterhuizen & Iannacchione, 2004). The project will continue into the foreseeable future, focusing on precursory micro seismic activity prior to large roof falls.

Previous and on-going NIOSH projects into stone mine stability have identified the potential hazards associated with slender pillars and excessive roof spans in underground stone mines. Guidelines were developed for avoiding potentially problematic ground conditions when designing room and pillar layouts. Issues such as roofbolt selection and micro seismic pre-cursors to failure have been investigated. However, these projects have not developed an explicit design methodology for determining safe roof spans and pillar dimensions for given rock mass conditions.

The following sections present a summary of the current state of knowledge in the three problem areas identified for this new project:

Pillars Strength

Dimensions of Pillars in Stone Mines:

A survey of 70 underground stone mines was conducted by NIOSH researchers during the late 1990's (Iannacchione, 1999). The room and pillar dimensions and other pertinent data were collected. The survey indicated that the average width-to-height ratio in underground stone mines was 1.77 during development and fell to 0.93 in benched areas. In the benched areas, 69% of the cases had width-to-height ratios of less than 1.0. Figure 4 summarizes the data.

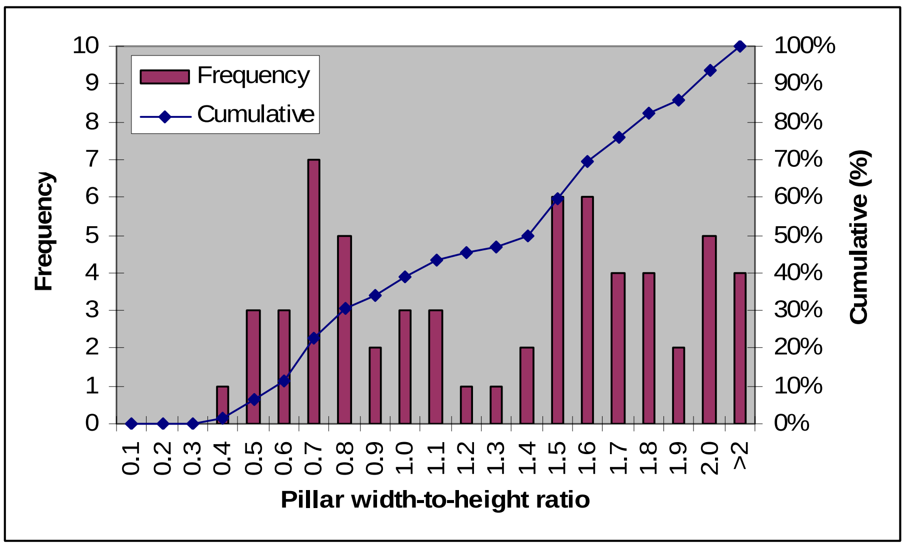

Figure 4: Width-to-height ratio distribution of underground stone mine pillars

Pillar Failure in Stone Mines:

Pillars in underground stone mines have been generally stable and provide adequate support to the overburden. Failure of pillars is rare and only two instances of widespread failure of pillar systems are on record. The fist case was the catastrophic failure of pillars in a limestone mine, in which an area of approximately 1000 ft x 2000 ft collapsed suddenly at a depth of cover of less than 200 ft, (Ropchan & Zipf, 1996). The area was mined with highly irregular pillar dimensions. Owing to the absence of details on the mine mining geometry and geotechnical parameters, it was not possible to investigate this case in greater detail.

A second instance of a large scale collapse in Kansas was investigated by Zipf & Schmuck, (1996). In this case the pillars were square, 25 ft wide by 17 ft high and were located under depths of cover of 100-200 ft. An area of approximately 4 acres collapsed over a weekend. The report concludes that the collapse was caused by a “wide area roof fall” and not pillar failure. Punching of the pillars into weak floor and roof rocks is thought to have caused the fall. This case highlights the importance of considering both roof and floor competence in pillar system design.

During the NIOSH survey of stone mine workings in the late 1990’s, a total of four instances of localized pillars failure were observed. Fortunately, none of these cases resulted in the large scale collapse of the overburden (Iannacchione, 1999). An evaluation of the pillar stress at failure of these four cases indicated that the pillar strength was highly variable. The width-to-height ratios were less than 1.25 in all four cases, highlighting the sensitivity of slender pillars to local rock mass conditions.

Guidelines for pillar layout design have been published by NIOSH (Iannacchione, 1999) in which it was noted that pillars with width to height ratios of less than 1.25 can fail if they are subject to overburden loads of greater than 200m or extraction ratios in excess of 0.83.

Pillar design methods:

Pillar strength has been widely researched for several decades. Most of the research has been directed towards coal mine pillars and some of it has transferred to hard rock mining. In broad terms it has been found that pillar strength is positively related to the strength of the rock forming the pillar and inversely related to the slenderness of the pillar. Slender pillars are weaker than squat pillars. Pillar design methodologies can be divided into three types (modified after Potvin, 1985):

- Heuristic method, in which an educated guess of required pillar dimensions is made based on “what worked before might work again”. This is the least sophisticated method and does not consider the strength or loading conditions of pillars. Provided the rock mass and loading conditions remain similar, this approach can be successful. It appears that many room and pillar layouts in stone mines are designed using a heuristic approach.
- Empirical design, which relies on experiment or experience. The difference from heuristic methods is that case histories are studied and strength relationships derived. The relationships can then be used to design pillars in similar conditions as the experiments or case histories. Examples are the Mark-Bieniawski equation for coal pillars, developed in the United States (Mark 1999), the Salamon-Munro equation developed for South African coal mines (Salamon & Munro, 1967) and the Hedley & Grant (1972) equation developed for uranium mines in Canada. Empirical methods have found wide acceptance in coal and hard rock mining practice world-wide.

- Analytical methods which are based on a mathematical description of the mechanical behavior of rock. Methods proposed by Wilson (1972) and Barron (1992) are well known examples. These methods, while providing insight into pillar mechanics, have not found acceptance in practice, most likely owing to the requirement for input parameters that are difficult or impossible to obtain.
- Numerical modeling, in which advanced numerical techniques are used to simulate pillar loading and rock mass response. These methods have been used in coal mining (Gale, 1999) and metal mines (Lunder, 1994) where pillar geometry is highly irregular and loading conditions are difficult to obtain. Modern modeling techniques allow sensitivity to specific conditions, such as through going joints or weak bands, to be evaluated (Iannacchione, 1999). Numerical models play an increasing role in site specific pillar design.

Pillar design methods developed for coal and metal mines are not directly applicable to stone mines, especially for the low width-to-height ratio pillars found in stone mines. Most empirical databases of pillar failure contain few, if any cases in which the width-to-height ratio is less than 1.0, rendering the equations inaccurate in this range.

Stability issues with pillars at low width to height ratios

Pillars with low width to height ratios are sensitive to the effect of through-going discontinuities. The results of numerical models showed that the strength of pillars with a width-to-height ratio of 1.2 can drop by about 50% if through-going joints at 45° are introduced (Iannacchione, 1999). This is part of the problem facing benching operations. The development pillars may be initially be stable, but once benching is carried out, the strength is reduced significantly and the pillars can yield. Figure 5 shows development and benched pillars, the increased height of the benched pillars will result in a significant reduction in strength. This phenomenon can explain several instances where mines have had to abandon benching operations because the rock conditions had become unstable.

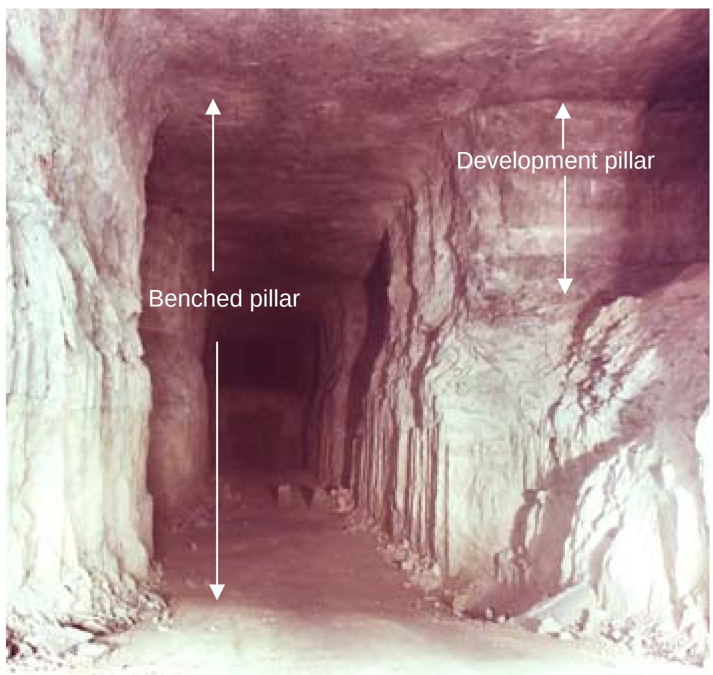

Figure 5: Illustration of development and benched pillars

A further problem with slender pillars is that they are more likely to fail in a catastrophic manner. The problem of cascading pillar failure has been addressed extensively in the literature, especially in relation to coal mine pillars, (Salamon 1970, Zipf, 1992, Galvin, 1992). The sudden collapse of the Coalbrook Colliery in 1960 in South Africa, with a loss of 437 lives was attributed to this type of failure, in which a single pillar fails, it overloads the adjacent pillars, which also fail, and set off a chain reaction of failures. The issue at stake is the rapid loss of strength of slender pillars once they start to fail. A squat pillar on the other hand loses it strength much more gradually and is less likely to fail catastrophically. In coal mine workings, catastrophic failures have occurred with pillar width to height ratios of between 1.0 and 2.8. The existence of large numbers of pillars in stone mines with width-to-height ratios of less than 1.0 is a concern that will be addressed by this research project.

Catastrophic failure is also dependent on the stiffness of the overburden which acts as the loading system that drives the pillars to failure, (Salamon, 1970). As the lateral extent of a mining panel increases, the loading system becomes less stiff and the likelihood of catastrophic failure is increased. In stone mines, where the width of mining panels can be several times the depth of cover, the loading system will therefore be “soft”, increasing the potential for catastrophic failure.

Roof Span Design in Bedded Rock

Roof span dimensions and support in stone mines

The limestone rock mass in US stone mines can be very competent allowing relatively large roof spans to remain stable. In the US underground stone mines the average roof span is 43 ft and spans of up to 60 ft were recorded during the NIOSH survey of stone mine workings in the late 1990’s. The distribution of roof spans is presented in Figure 6. Roof spans of 35 ft to 50 ft account for 69% of all roof spans observed. Of the mines

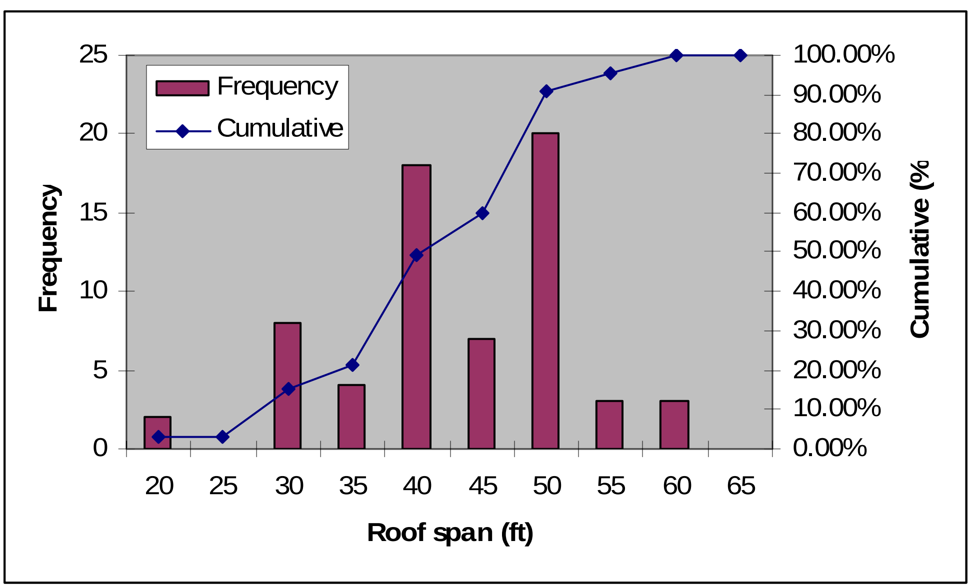

Figure 6: Distribution of roof spans in underground stone mines

surveyed, only 24% used regular bolting to support the roof while 21% did not use any support. The remaining 55% used spot bolting.

The immediate roof in underground stone mine workings usually consists of rock beams formed by the horizontal layering of the limestone. These beams vary in thickness and competence, depending on the rock strength and the bedding and joint frequency in the limestone formation. Stability of the roof is usually determined by the stability of the first beam in the roof. Stone mine operators often select specific horizon in the limestone formation, so that a strong beam of adequate thickness forms the immediate roof.

Roof failures in stone mines

High horizontal stresses have been identified as a cause of roof beam failure in several US stone mines (Iannacchione et al., 1997). High stress conditions have been observed in stone mines in western Pennsylvania, eastern Kentucky, West Virginia and southwestern Virginia. The high horizontal stresses are caused by tectonic loading of the Mid-North American Plate (Zoback, 1992) and have been measured in many of the area's coal mines (Mark & Mucho, 1994). Figure 7 shows a typical large roof failure caused by excessive horizontal stresses in a limestone mine. The stresses can cause failure of the intact rock forming a beam, mobilize shear along pre-existing joints and cause buckling of the beam in compression.

In lower stress conditions, roof beam failure can occur as a result of bucking under gravity loading, or loss of integrity owing to inclined joints. Simple plug failure in the absence of external stresses can also occur, which can result in subsidence and sinkhole formation.

Stone mine roof span design should therefore consider the characteristics of the immediate roof rocks, their stability under gravity loading and the effect of horizontal stress.

Roof Span Design

Techniques for designing stable roof spans in underground mining have followed a similar path as that of pillar design, relying much on empirical relationships developed from a study of stable and unstable cases. Analytical methods have also enjoyed recent attention, with the expansion of classical beam theory to the special case of rock

Figure 7: Roof fall caused by excessive horizontal stress in a limestone mine

beams. Each of these approached are discussed below.

Empirical Methods of Roof Span Design

A widely accepted approach to determine stable roof spans is the application of empirical relationships between roof spans and rock mass classification. The well known Rock Mass Rating (RMR) system (Bieniawski, 1989) relates the RMR to stable roof spans and stand-up time. Similarly, the Q-System of rock mass classification (Barton et al., 1974) relates the rock mass quality “Q” to excavation span and support requirements. These relationships were largely developed from civil engineering case histories, and are not directly applicable to mining applications. A further problem with the RMR and Q-systems of rock classification is that they are poorly suited to classifying bedded rocks. This has resulted, for example, in the development of the Coal Mine Roof Rating (CMRR) by Molinda & Mark (1994) which was specifically designed for classifying bedded rocks in US coal mines.

In hard rock mining, Laubscher (1990) developed a modified version of RMR called the Mining Rock Mass Rating (MRMR) in which stable and caving case histories were used to develop a relationship between MRMR and excavation dimensions. The chart is based on non-entry mining conditions, meaning personnel do not enter into the openings. A stable configuration for non-entry mining is unlikely to be satisfactory for entry mining methods such as room and pillar mining where a small rock fall from a great height can cause serious injuries to personnel.

The Matthews stability chart (Matthews et al., 1980) and several modifications (Potvin, 1988, Stewart and Forsyth, 1995) are based on the Q-system of rock classification. The chart was developed using Canadian open stoping case studies in metal mines, which are also non-entry excavations. The method modifies the Q-rating of a rock mass to account for stress, orientation and failure mode. The attraction of this approach is that an adjustment can be made to account for bedded strata parallel to the roof. Since the design chart has been based on metal mining case studies, it is not likely to be directly applicable to stone mines. In addition, the higher requirements for stability in entry mining, versus non-entry mining, are not addressed. Nevertheless, the method of accounting for roof bedding appears to be well suited to modification for stone mining applications.

The empirical approach is likely to be equally valid for stone mines. The approach used for the Matthews stability chart appears to be suitable for modification to make it applicable for stone mines.

Analytical Methods of Roof Span Design

Elastic beam theory can be used to evaluate the stability of rock beams in the roof of stone mine excavations. Beam deflection and the development of tensile and shear stresses as well as the potential for beam buckling can be calculated (Jaeger & Cook, 1979). However, the theory assumes elastic behavior and the absence of defects in the beam. In practice, rock beams typically contain joints and other defects which are not included in the simple elastic equations. A more robust approach has resulted from the recognition that a cracked beam maintains stability through a compressive arch that forms within the beam, called a “voussoir arch”. Beer & Meek (1982) presented an updated version of the voussoir arch model. The beam fails realistically when the arch either “snaps-through”, fails by crushing the abutments or simply drops out under shear. The model was recently re-visited and improved (Diederichs & Kaiser, 1999) who found that it provides similar results as the Matthews stability chart, except that now lamination thickness can be explicitly accounted for. This appears to be a promising approach for predicting stone mine roof stability.

Temperature and Humidity effects on Roof Stability

The effects of temperature and humidity changes on roof stability has been researched extensively in coal mines (Statenham & Radcliffe, 1978; Pappas, Bauer & Mark. 2000), for example a doubling of the rate of roof falls during the summer months has been reported in a Northern Appalachian coal mine (Mark et al., 2004).The weatherability of rocks has been recognized as a significant factor in coal mine roof stability (Unrug & Pagett, 2003).

The limestone rocks in underground stone mines are not as susceptible to weathering as the some of the weaker coal measure rocks. Slake durability tests on Ohio limestone rocks have shown high resistance to weathering (Bawden & McCreath, 1979). Tests on non-limestone roof rocks from roof falls an underground limestone mine in central Kentucky (Unrug, 1997) showed a moderate degree of weatherability. The presence of these weaker rock types as interbeds in limestone or in the immediate roof of a limestone formation can affect roof stability if they are weakened by exposure to moisture in the mine air. Measurement of roof deflection and rockbolt loading showed a direct correlation between mine air temperature and roof response (Dolinar & Mucho).

The temperature and humidity in underground mines fluctuates with the seasons. In the summer months the moist outside air is cooled as it enters the mine and can cool below the dew-point. The excess moisture will condense onto rock surface and in cracks within the rock. In the cold dry winter months, moisture is extracted by the low humidity mine air. These fluctuations in moisture content can lead to deterioration of weaker water sensitive rock types.

d) Research Design and Methodology

The research project will address the need for methodologies to determine:

- the minimum pillar width-to-height ratio;
- maximum roof span dimensions, and
- the effect of temperature and humidity on roof and rib stability in underground stone mines.

A combined empirical and analytical approach will be followed, in which rock mass conditions, successful and unsuccessful mine designs, laboratory testing, field monitoring and numerical modeling will be used. The project tasks include field surveys and field data collection at operating stone mines, monitoring of temperature and humidity, stress measurements and displacement monitoring, analysis of past failures as well as stable layouts, laboratory testing at PRL, data analysis and development of relationships between important rock mass properties and excavation stability in stone mines. These relationships will be presented as design charts which will act as guidelines for the maximum roof spans and minimum pillar widths in underground stone mines. The basis for the design charts is expected to be rock classification, using one of the established classification methods, with additional modification parameters tailored for roof span and pillar design.

The approach that will be followed for pillar design is expected to be similar to the method developed by Ryder & Ozbay, (1990), in which pillar strength is determined by applying a series of strength correction factors to the basic rock material strength. Correction factors for “shape effect”, “width-to-height ratio effect”, “foundation damage” and “creep” can be incorporated into the design. Additional factors such as bedding strength and joint orientation will be considered. Geotechnical characterization of the different limestone mining areas, assessment of excavation performance, back analysis of stable and failed cases and numerical modeling will be employed to identify the important factors and develop relationships to be included in the pillar design methodology.

The development of a design chart for maximum roof spans will follow a similar approach, most likely developing a design chart similar to the Matthews Stability Chart in which a basic rock classification is modified by a number of factors to account for roof stability. Factors that are likely to be considered are bedding spacing and horizontal stress. The field data collection and rock mass characterization efforts together with numerical modeling will be used to identify the important parameters and develop the relationships in the design chart.

The investigation of temperature and humidity effects on excavation stability will be based largely on field monitoring and laboratory testing. Relationships will be developed between the observed roof and rib behavior, rock properties and the humidity/temperature variations. Depending on the outcome, a humidity/temperature factor can be included in the roof span design methodology.

The project will run for four years with eight specific tasks:

Task 1: Geotechnical Data and Mine Characterization
The geotechnical setting of the underground stone mines needs to be characterized since this will form the basic input to the roof span and pillar design methodologies. Site visits will be made to selected mines in the various stone mining districts in the Eastern and Midwestern states. The site visits will include quarries where underground mining has been unsuccessful owing to poor rock conditions. These cases are expected to provide bounding limits to roof and pillar stability. A total of 30 mines will be visited over a two year period. Based on currently available data, approximately 22 mine operations have pillar width to height ratios of less than 1.0. These mines are potential cases of pillar instability. Poor roof conditions are expected to be found at almost every mine operation, providing approximately 30 cases of poor roof conditions for the database. Care will be taken to identify "abnormal" rock conditions that may result in specific cases of instability at the different mine operations. A field data collection sheet will initially be developed and tested at the Lake Lynn Laboratories. The following data will be collected:

- **Geological characteristics:** The regional geology of each mine site will be reviewed from published literature and local data available at the mine site. The objective will be to identify any regional characteristics such as folding or faulting that may affect the mine stability. The succession of the various rock formations will also be determined from the literature. The immediate roof and floor lithology will also be determined from inspection and available records.
- **Field mapping and rock classification**: During each site visit, rock mass classification will be carried out, ideally at three different locations in each mine. Mapping of major joint orientations and frequencies as well as bedding characteristics will be carried out. A dataset will be collected that allows any of the major classification methods to be applied.
- **Mine layout parameters**: During the site visits, mine layout parameters such as room and pillar dimensions, benching height, heading orientation and depth of cover will be collected. Site specific measurements will be made at each location where rock classification is conducted**.**
- **Excavation performance assessment**: At each rock classification site a visual assessment of the local rock conditions and excavation performance will be made. Categories for quantifying the rock conditions will be developed which will include stress effects, blasting and rock defects. In addition, an assessment of the overall roof and rib stability in the mine will be made.
- **Failure mode assessment:** Where roof or rib failures are observed an assessment of the type of failure and likely causes will be made. A list of typical failure modes and causes will be developed so that each observed failure can be categorized.
- **Field monitoring**: Field monitoring activities will be conducted to investigate specific stability issues encountered during the field data collection activities. Potential sites for detailed monitoring or measurements will be identified. Monitoring activities will depend on the specific aspect that requires investigation and can include stress measurements using the maxi-frac system, stress change

monitoring using vibrating wire strain cells to assess pillar stability and displacement monitoring using extensometers or roof-floor convergence meters to assess system stability. An allowance has been made in the budget for measurements to be carried out at two different sites.

- **Laboratory testing of rock properties:** Rock samples or drill core, if available, will be collected at the mines to determine the strength of the limestone and surrounding rocks. Where possible, samples of the immediate roof rocks will be obtained. Testing of rock strength and mechanical properties will be carried out at the PRL laboratories. The weathering characteristics will be tested using the slake durability test or other appropriate testing methods.

The major outcome expected from the task is a quantitative assessment of the geotechnical characteristics of the limestone formations in the Eastern and Midwestern stone mines as well as an evaluation of the performance of the room and pillar designs in the various geotechnical settings. These data will allow an assessment to be made of the important factors that affect roof and pillar stability. A peer-reviewed document describing the geotechnical characteristics and pillar and roof performance in underground stone mines will be prepared.

Task 2: Back analysis of pillar performance

The development of an empirically based pillar design chart requires that numerous cases of stable and unstable pillars should be evaluated. The field data collected during Task 1 will form the basis for the back analyses. The analyses described below will be carried out during the first two years of the project, providing input to the development of a pillar design chart.

- **Analysis of failed pillar systems:** Although pillar failures are rare in stone mines, some instances of unstable pillars were recorded during the NIOSH survey of stone mines in the late 1990's. Four cases of isolated unstable pillars were recorded. In addition two cases of large scale collapse of workings have been reported in the literature. Geotechnical and other pertinent data on each of these cases will be collected through site visits, as part of Task 1,

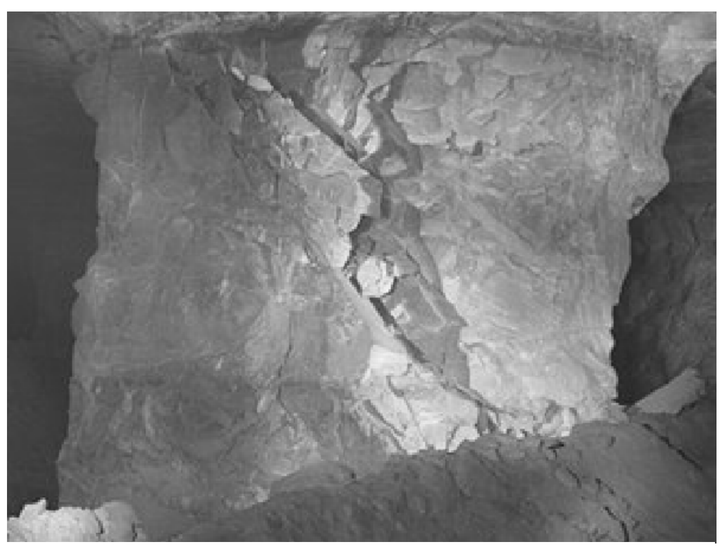

Figure 8: Failed pillar showing through-going fracture

or from literature reviews. An analysis of likely pillar loads and pillar strength will be conducted. An example of a failed pillar is shown in Figure 8.

- **Analysis of unsuccessful benching operations:** NIOSH researchers have observed that benching operations often result in poor rock conditions forcing the mines to abandon benched areas. Site visits to a selection of these areas will be made to characterize the rock mass and obtain site specific mining data as part of Task 1. Analyses will be carried out to evaluate the effect of benching on stress distributions in the benched pillars and the surrounding pillars.
- **Analysis of stable pillars:** Both failed and stable cases are required to develop a pillar strength relationship. Analysis of slender pillars that have not failed will provide important data on their strength characteristics. The field and geotechnical data collected as part of Task 1 will be used to carry out simple analyses based on tributary area theory.

The outcome of this task will form the empirical basis for developing a pillar design chart. A document on the performance of stone mine pillars in various geotechnical settings and critical factors affecting their strength will be prepared for publication.

Task 3: Evaluate pillar strength at low width-to-height ratios

A pillar design methodology for stone mines must be particularly accurate at low width to height ratios. Many stone mine operations are located at a shallow depth of cover and slender pillars can be used. The lack of large numbers of failed stone mine pillars will make it difficult to assess the lower limit of their strength from case histories. It will be necessary to supplement the field studies with numerical models and experience from other types of mining to enhance our understanding of pillar strength at low width-to-height ratios. The task will comprise of the following activities:

- **Review of existing pillar design methods and relevance to low width-to-height ratio pillars**: Pillar strength equations have been developed from large numbers of case histories in hard rock metal mines. These case histories and the developed equations will be reviewed and evaluated for their relevance to stone mine pillar design. Particular attention will be paid to their validity and robustness in the lower width-to-height ratio ranges (<1.25). A pillar strength equation will be selected or modified for application to stone mine pillars.
- **Numerical analysis of low width to height ratio pillars**: Numerical models will be used to assess the strength of slender pillars under various loading and geotechnical conditions. The effect of through-going structures, foundation materials, contact properties and rock mass variability will be considered. The results will be compared to output of the empirical pillar strength equations and used to assist in selecting or developing an appropriate equation.
- **Reliability analysis of a system of pillars with a low width to height ratio**: Based on the outcome of the numerical models and review of pillar strength equations, a reliability analysis will be carried out to assess the risks associated with low width-to-height ratio pillars. The output will be used to assist in identifying the necessary safety factor for pillars at low width-to-height ratios.

The major outcome of this task will be an improved understanding of the factors affecting pillar strength at low width to height ratios and will provide needed input to the development of a pillar design methodology. The findings will be presented in a peer reviewed publication.

Task 4: Analyze data and develop pillar design guidelines
The results of tasks 1 through 3 will be collated and evaluated to develop a pillar design methodology and a design chart. It is expected that the method will be based on an initial rock classification followed by the application of adjustment factors for the important parameters that affect pillar strength in stone mines. The focus will be to quantify pillar strength and performance at low width-to-height ratios. The activities under this task include:

- **Develop rock classification adjustments for pillar design:** Based on a review of all the collected case studies, the numerical models and evaluation of pillar strength equations, a hierarchical arrangement of factors affecting the strength of pillars will be made. Appropriate relationships between each important parameter and pillar strength will be established from field data, numerical models and existing pillar strength equations. For example, the effect of joint dip might be based on a relationship developed from numerical model results. Factors such as immediate roof and floor stability are also likely to be included.
- **Develop pillar design methodology and layout guidelines:** The rock mass strength modifications and empirical pillar performance data will be used to develop a relationship between geotechnical characteristics and pillar strength. Statistical techniques, such as minimization can be used to define appropriate parameters for the pillar design equations. It is likely that a pillar strength chart showing strength for different geotechnical settings will be developed. The procedures for developing input for the pillar design chart will be described and a design methodology developed. The methodology will also address situations in which adequate data are not available for the design, typically by recommending the user to assume conservative inputs. The layout guidelines will be based on observations made during the site visits and will incorporate guidelines related to excavation orientation and pillar patterns from the literature. Validation of the developed method will be carried out by testing the method at selected mine sites and comparing the "predicted" pillar dimensions to performance of actual pillars. A document will be prepared that describes the pillar design methodology and includes layout guidelines. The document will be circulated for peer review and discussion with MSHA and other stakeholders.

The task will produce pillar design guidelines for the specification of pillar width-to-height ratios in stone mine workings. The focus will be on pillars with low width-to-height ratios and, depending on the outcome, may specify a lower limit to the width-to-height ratio for pillar design. This outcome is expected to have a significant impact on the risk of instability in shallow stone mine workings. A peer reviewed report for publication in major mining/rock engineering journal will be prepared. The results will in addition be presented at industry conferences and seminars.

Task 5: Monitor and evaluate temperature and humidity effects

This task will provide specific measurements on mine environment variables including production and ground fall locations documenting a comprehensive characterization of these variables and unknowns at two to three mine sites over a period of three years. The task will require an on-going low level of activity over a period of three years, while field monitoring continues. During the fourth year, the findings will be summarized and, depending on the results, appropriate guidelines for identifying hazardous conditions related to temperature and humidity fluctuations will be developed. The plan includes 3 principal activities:

- **Field instrumentation at selected mine sites:** Underground Mine Site Identification, Instrument Package Installation, and Data Collection and Assessment. Full cooperation from the mine operator and mine worker is required for successful instrumentation installation, maintenance, and data collection. A presentation and explanation to the mine workforce of the intended work will preface the installation stage, as needed. Location, budget, and mine conditions will be evaluated during the selection process. Installation will include sag monitors, convergence stations, temperature, and humidity instruments. Two or possibly three mine sites will be monitored for at least 12 months each.
- **Laboratory testing of weatherability:** The weatherability of the limestone and surrounding rocks at the selected mine sites will be tested at the PRL rock mechanics laboratory. Slake durability tests or other appropriate tests will be used to quantify the sensitivity of the mine rocks to the presence of moisture.
- **Analysis of data and development of relationships:** Field and laboratory test results will be evaluated and correlations made with observed excavation stability. The findings will be reported at interim stages at industry seminars with a final report being prepared and published in the fourth year of the project.

The outcome of this task will be a clarification of the issues related to temperature and humidity effects on stability in stone mines. A publication on the results of this study together with any appropriate guidelines will be prepared for publication at industry forums.

Task 6: Analyze roof span stability in stone mines

The factors affecting roof span stability and associated failure mechanics in stone mines will be evaluated based on the data collected during Task 1. Geotechnical conditions and failure modes will be categorized for further analysis and inclusion into the proposed design methodology. The original premise of relating roof spans to rock mass properties will be reviewed in the light of the collected field data. Published empirical and analytical techniques for the prediction of stable spans in underground mines will be tested against the data to determine which approach is the most likely to replicate the experience in stone mines. Numerical models of the various scenarios will be evaluated to improve understanding of roof failure mechanics. The activities under this Task are as follows:

- **Review of roof span design methods and test applicability to stone mine design:** The existing roof span design methods will be tested against the field data to identify the most appropriate approach for developing a roof stability chart for stone mines. The premise of relating roof spans to rock mass data will be reviewed. Methods that will be tested include the voussoir arch approach, simple elastic beam methods and rock classification methods.
- **Evaluate field data to identify causes of roof instability**: The field data collected as part of Task 1 will be categorized according to the assessed failure mechanism and the geotechnical characteristics. Conditions leading to certain types of failure will be identified and where possible, relationships between stable spans and specific geotechnical conditions identified. This will form the basis for developing a roof span stability chart.
- **Numerical analysis to evaluate beam stability and failure mechanisms:** Numerical models of the different roof categories will be evaluated to improve understanding of the likely failure mechanisms. For example, the effect of weak bands overlying a strong roof beam, the effect of thin beams overlying thicker beams, the effect of high horizontal stress on beam deflection will be evaluated. The results will assist in developing relationships between the different geotechnical categories and roof span stability.

The task will produce a categorization of causes of roof instability in stone mines, an improved understanding of the mechanisms involved in the failures and an assessment of the applicability of existing roof span design methods. Specific issues for further field monitoring and data collection will be identified. The results will form part of the input to develop a design approach for stone mines. A document summarizing the outcomes will be prepared for publication at an appropriate forum.

Task 7: Case studies of roof span stability
A number of field sites visited during the data collection stage will be identified for detailed case study analysis. Sites that are likely to be evaluated may include areas in which the failure mechanisms are not clear or to clarify the roof behavior in a specific geographic area. More detailed data on the rock mass properties, field stresses and mining parameters will be collected for analysis. If appropriate, field monitoring will be conducted of roof behavior and associated rock mass response. Allowance has been made in the budget for two field monitoring sites, including the measurement of field stresses and roof deflections. The activities under this task are as follows:

- **Collect data for case studies**: Sites for detailed case studies will be identified and arrangements made with mine operators for site access and conducting measurements. More extensive rock classification and rock strength testing will be done to fully quantify the geotechnical conditions. Mine records will be inspected to obtain data on mining methods, mining sequences and blasting practices. Records of roof falls and their effect on mine operations and safety will be collected. The data will form the basis for a comprehensive evaluation of roof stability at the mine site.

- **Conduct field measurements**: The observational data at the case study sites will be supplemented by field measurements. A program of field measurements will be designed appropriate for the local conditions and specific parameters identified for investigation. The types of measurements could include: in-situ stresses determination using the maxi-frac system, roof beam deflection measurements using extensometers or roof-floor closure meters, rock bolt load measurements and damage mapping in the excavations.
- **Analyze case studies:** The field data will be evaluated and analyzed. Numerical models of the case study sites will be developed to assess potential failure mechanics and to calibrate the models.

The task will provide well documented case studies in which roof stability and failure mechanisms are quantified. The improved understanding provided by these case studies will be used to validate the design procedures. The case study results will be written up in one or more documents that will be published in industry forums and in the technical literature.

Task 8: Develop guidelines for selecting maximum roof span dimensions
The final task of the project will be to collate the results of the investigations into roof stability and develop a roof span design methodology. The methodology will have the objective to account for local geotechnical conditions in roof span selection. The methodology is therefore expected to include a basic rock mass classification with adjustment factors for specific geotechnical conditions. The task will be carried out as follows:

- **Establish relationships between geotechnical parameters and roof stability:** Based on the field surveys and case study sites, the important factors affecting roof stability will be identified using statistical analysis. The results of numerical and analytical models will be incorporated into the evaluation. Relationships will be developed to rate the relative importance of factors such as beam thickness, joint frequency and horizontal stress on roof stability. The results will guide the selection of factors for inclusion into the design methodology.
- **Develop roof span design charts and guidelines for mine layout:** A roof span design chart will be developed that allows local geotechnical parameters to be included in the design. This will be accomplished by incorporating the important factors that affect span stability into a classification scheme. Adjustments for the effect of mining parameters such as bolting, blasting practice and excavation orientation are likely to be included. Validation of the developed method will be carried out by testing the method at selected mine sites and comparing the "predicted" roof spans to performance of actual spans. Depending on the outcome of this research, the potential for specifying an upper limit to roof spans in

underground stone mines will be investigated. A guideline document will be prepared which will incorporate the developed design method as well as established excavation design principles. The document will be submitted for expert review and input by MSHA and other stakeholders.

The major output of this task will be the document presenting the guidelines for roof span design in underground stone mines. The results will be published through industry seminars and peer reviewed publication.

PROJECT SCHEDULE

FY 2005

Task 1 - Geotechnical Data and Mine Characterization
- Collect geotechnical and mining related data at fifteen mines
- Conduct laboratory tests of rock properties

Task 2 – Back Analysis of Pillar Performance
- Evaluate two cases of unsuccessful pillar systems

Task 3 – Evaluate pillar strength at low width-to-height ratios
- Review existing pillar design methods and their relevance to low width to height ratios
- Start numerical analysis of pillars with low width to height ratios

Task 5 – Monitoring of temperature and humidity effects
- Develop program and install instrumentation at first mine site
- Monitor mine climate changes and roof/rib stability

FY 2006

Task 1 - Geotechnical Data and Mine Characterization
- Collect geotechnical and mining related data at fifteen additional mines
- Conduct laboratory tests of rock properties
- Conduct field stress measurements at two sites

Task 2 – Back Analysis of Pillar Performance
- Evaluate two additional cases of unsuccessful pillar systems
- Evaluate two cases of unsuccessful benching operations
- Evaluate stable pillar layouts

Task 3 – Evaluate pillar strength at low width-to-height ratios
- Numerical analysis of pillars with low width to height ratios
- Reliability analysis of pillar systems with low width-to-height ratios

Task 5 – Monitoring of temperature and humidity effects
- Develop program and install instrumentation at second mine site
- Monitor mine climate changes and roof/rib stability

Task 6 – Analyze roof span stability in stone mines
- Review of roof span design methods and test applicability to stone mine design

Task 7 – Case studies of roof span stability

- Identify and collect data at a case study site
- Conduct field measurements at a case study site

FY 2007

Task 4 – Analyze data and develop pillar design guidelines

- Develop rock classification adjustments for pillar design
- Develop pillar design methodology and layout guidelines
- Validation of methodology

Task 5 – Monitoring of temperature and humidity effects

- Develop program and install instrumentation at third mine site
- Monitor mine climate changes and roof/rib stability

Task 6 – Analyze roof span stability in stone mines

- Review premise of relating rock mass conditions to roof span stability.
- Numerical analysis of roof span stability and failure mechanisms
- Evaluate field data and identify causes of roof instability

Task 7 – Case studies of roof span stability

- Identify and collect data at second case study site
- Conduct field measurements at case study sites

FY 2008

Task 5 – Monitoring of temperature and humidity effects

- Evaluate data and prepare final report and guidelines

Task 8 – Develop guidelines for selecting maximum roof span dimensions

- Establish relationships between geotechnical parameters and roof stability
- Develop roof span design charts and guidelines for mine layout
- Validation of methodology

RESOURCES

Laboratory:

Pittsburgh Research Laboratory

- Rock Mechanics Testing Facility – Rock strength and mechanical properties testing
- Rock Engineering Software – Analysis of roof and pillar failure mechanics
- Rock Mechanics Instrumentation – Instruments for measuring and recording in-situ stresses, rock displacement, temperature and humidity.

Lake Lynn Laboratory

- Access to underground mine for testing of data collection techniques and monitoring systems

Mine Sites:
Commercial Mines

- Underground mine sites in eastern and mid-western US for data collection
- Mine sites for underground monitoring and measurements, to be identified during first year of project

Clinical: none

Animal: none

Other: none

Major equipment: none

e.) Literature Cited

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f.) External Consultants - none

g.) Mission Relevance

Fall of ground accidents have been the largest cause of fatalities in underground stone mines over the past decade. Injury rates from ground falls in underground stone mines are higher than other underground mines, highlighting the need for methods of improving roof and rib stability. This project has the objective to eliminate hazardous ground conditions from underground stone mines, which directly addresses our mission to "Eliminate occupational diseases, injuries and fatalities from the mining workplace through a focused program of research and prevention".

h.) Short Project Summary

The objective of this project is to develop design guidelines for maximum roof spans and minimum pillar dimensions in underground stone mines. The effect of temperature and humidity on excavation stability will also be assessed and incorporated into the design guidelines. The project will provide assistance to mine designers and operators in selecting excavation dimension based on an engineered approach, rather than trial and error methods.

Geotechnical and mining parameters will be collected from thirty underground stone mining operations in the Eastern and Midwestern States. The field data will be supplemented by measurements and monitoring at selected case study sites. Numerical model analyses and evaluation of existing pillar and roof span design techniques will be conducted to develop relationships between geotechnical parameters and stability. Monitoring of temperature and humidity changes and associated roof and rib stability issues will be conducted at three mine sites.

The results will be evaluated and guidelines for pillars and roof span design developed allowing local geotechnical parameters as well as mining inputs to be included in the design process. The outcome will be better engineered underground mines and the elimination of some of the potentially hazardous ground conditions found in underground stone mines.

DETAILED PERSONNEL PLAN

Name and Degree	Role on Project	FY2005	FY2006	FY2007	FY2008
Onboard:		%	%	%	%
R Güner Gürtunca PhD (Mining Engineering)	Project Consultant (Acting Director, NIOSH Pittsburgh Laboratory)	10	10	10	10
Stephen C Tadolini PhD (Mining Engineering)	Controls overall project direction and performance (Acting Branch Chief)	10	10	10	10
Anthony T Iannacchione PhD (Civil Engineering)	Geotechnical and mining engineering, project design and evaluation of outputs (Acting Team Leader Geotechnical Engineering)	20	20	20	20
Gabriel S Esterhuizen PhD (Mining Engineering)	Principal investigator (Senior Service Fellow)	80	80	80	80
Dennis R Dolinar MS (Mining Engineering)	Mining and geotechnical project design, field studies, data analysis and development of outputs (Mining Engineer)	50	50	50	50
Leonard J Prosser BS Geology	Conducts studies of temperature and humidity effects and coordinates r2p activities (Physical Scientist)	70	70	70	70
John L Ellenberger MS Geology	Data analysis, numerical modeling (Research Geophysicist)	50	50	50	50
David C Oyler BS (Mechnical Engineering)	Field instrumentation design, implementation and analysis. (Mechanical Engineer)	20	40	40	20
David L Dwyer	Rock testing, instrumentation (Engineering Technician)	50	50	50	50
Craig S Compton	Field instrumentation specialist (Engineering Technician)	0	40	40	0
Onboard Subtotals:		3.60	4.20	4.20	3.60
New Hires					
Numerical modeler	Develop and run numerical models and analyze outputs	80	80	80	80
New Hires Subtotal:		0.80	0.80	0.80	0.80
Totals		**4.4**	**5.0**	**5.0**	**4.4**

PROJECT BUDGET SPREADSHEET

Project Budget Guidelines for Eliminating Hazardous Ground Conditions from Underground Stone Mines

			2005			2006			2007			2008		
Travel	Meeting/Purpose	Personnel	Registration	hotel+perdiem	subtotal	Registration	hotel+perdiem	subtotal	Registration	hotel+perdiem	subtotal	Registration	hotel+perdiem	subtotal
	Temperature & Humidity Monitoring													
		Prosser		475			475			475			475	
		Compton		475			475			475			475	
	Convergence monitoring													
		Prosser		475			475			475			475	
		Compton		475			1,300			1,300			475	
	Mine data collection/monitoring													
		Iannacchione		1,300			1,300			650			520	
		Esterhuizen		2,600			2,600			1,300			520	
		Prosser		2,600			2,600			1,300			520	
		Dolinar		2,600			2,600			1,300			520	
		Oyler		500			2,600			2,600			520	
		Compton		650			2,600			2,600			520	
	Ground Control Conf.													
		Esterhuizen	320	200		320	200		320	200		320	200	
		Prosser	320			320			320			320		
		Ellenberger	320			320			320			320		
	Stone Safety Seminar													
		Iannacchione		275			275			275			275	
		Prosser		275			275			275			275	
		Dwyer		275			275			275			275	
		Compton		275			275			275			275	
		Esterhuizen		275			275			275			275	
	Rock Mechanics Symposium													
		Esterhuizen	400	1,600		400	1,600		400	1,600		400	1,600	
					16,685			21,560			17,010			9,555
Software Purchase/Upgrades														
	Purchase Examine3D			1,500										
	Training PFC			5,000										
	Upgrade FLAC Software			3,800			3,800			3,800			3,800	
					10,300			3,800			3,800			3,800
Supplies	Type													
	FIeld supplies/connectors/tools			1,500			1,500			1,500			100	
	Batteries/film			100			100			100			50	
	Cablng			500			1,000			1,000				
	Lab testing supplies			500			1,500			500			100	
					2,600			4,100			3,100			250
Equipment														
	Roof sag equipment			2,500			2,500			2,500				
	Stainless wire			400			400			400				
	Extensometers/borehole monitoring			1,500			1,500			1,500				
	Dataloggers			5,000			5,000			2,000				
	Stress Measuring Equipment			8,000			5,000			6,000				
	Compass/Measuring equipment			2,000			2,000			1,000				
	Logging equipment/camera/lights			2,000			1,000			500				
					21,400			17,400			13,900			0
Seminars (r2p)														
	Stone Safety Seminar			800			800			800			800	
	Lake Lynn Live			500			500			500			500	
					1,300			1,300			1,300			1,300
Total					52,285			48,160			39,110			14,905